1

Hitless modem pool expansion at steady state.

FIELD OF THE INVENTION

The present invention relates to modem pools in general, and more particularly

5   to hitless modem pool expansion.

BACKGROUND OF THE INVENTION

Crosstalk interference between the receiving and the transmitting paths of different transceivers whose communications media are in physical proximity to one

10   another, such as is often experienced between different wires in a telephone wire bundle, is well known. The crosstalk in a telephone wire bundle depends on the number of interfering lines, and increases as the bandwidth that the signals occupy increases. In a modem pool environment where streams of data are distributed to many lines within a single bundle, and where the bundle is used exclusively by the modem pool, the crosstalk that the receivers

15   need to overcome is mainly generated by the transmissions that the modem pool itself generates. Since such a system has access to its own transmission characteristics, such information may be used to cancel the interference that leaks into the receivers, thus decreasing the noise floor of each receiver.

In classic crosstalk cancellation, a transmitter transmitting via one wire or wire

20   grouping (e.g., twisted pair) affects the receiver receiving via another wire or wire grouping. A hybrid circuit separates the received signal from the transmitted interfering signal, but since the hybrid cannot completely separate the transmit path from the receive path, some of the transmitted signal leaks into the receiver and becomes an interfering signal. A canceller then filters out the effect of the interfering signal, resulting in a

25   "cleaned" received signal. For a single modem, this problem may be addressed using classic echo cancellation techniques. In a modem pool environment where several modems transmit via a shared bundle, the canceller for each receiver must take into account all the interfering transmitters.

The addition of a modem to a modem pool that is operating at steady state may

30   cause a significant increase in the noise levels experienced by the currently-operating modems, since the crosstalk generated by the currently-operating modems is already being

cancelled, while the crosstalk interference that the new modem causes to the currently-operating modems is not cancelled until its crosstalk function is learned by the currently-operating modems. Until the currently-operating modems learn the crosstalk function of the new modem, the crosstalk generated by the new modem may cause severe degradation in

5   the reception quality of the currently-operating modems, increasing their bit error rate (BER), and possibly causing some currently-operating modems to lose synchronization and deactivate as a result.

The "hitless" addition of a new modem to a modem pool operating at steady state that does not significantly affect the existing noise environment of the modem pool

10   would therefore be advantageous.

SUMMARY OF THE INVENTION

The present invention provides for the "hitless" addition of a modem to a modem pool operating at steady state – "hitless" in that the crosstalk interference of the

15   added modem has little or no negative effect on the currently-operating modems in the modem pool. In the present invention a new modem is inserted into the modem pool but is not immediately used for transmitting data. Instead, it is used to learn the crosstalk it receives from the other currently-operating modems in the modem pool. Due to the reciprocal nature of crosstalk in this arrangement, this information may be used to

20   determine the crosstalk that the new modem will cause to the other modems. The modems in the modem pool may thus be informed of the crosstalk that the new modem will cause once it begins to transmit data, and they may adjust themselves to compensate for the additional crosstalk as soon the new modem begins to transmit.

In one aspect of the present invention in a communications system having a first

25   modem transmitting via a communications channel, a method is provided for adding a second modem for communication via the communications channel, the method including configuring the second modem for receiving communications via the communications channel, learning crosstalk caused by transmissions from the first modem via the communications channel to the second modem while the second modem is in a transmitting

30   state insufficient to cause crosstalk interference to the first modem in accordance with a predefined measure, deriving from the learned crosstalk an estimation of crosstalk that

would be caused by the second modem to the first modem when the second modem is in a transmitting state, configuring the first modem to cancel crosstalk according to the crosstalk estimation, causing the second modem to enter a transmitting state sufficient to cause crosstalk interference to the first modem in accordance with a predefined measure, and

5   causing the first modem to at least partially cancel crosstalk caused by the second modem in accordance with the crosstalk estimation.

In another aspect of the present invention the learning step includes learning by applying crosstalk cancellation to transmissions received by the second modem at a receiver of the second modem.

10   In another aspect of the present invention the learning step includes expressing the learned crosstalk as a transfer function.

In another aspect of the present invention the learning step includes learning while the second modem is in a non-transmitting state

In another aspect of the present invention the deriving step includes applying an

15   adjustment to the crosstalk estimation to compensate for a difference in a characteristic of the transmissions.

In another aspect of the present invention the deriving step includes deriving the estimation from a reciprocal value of the learned crosstalk.

In another aspect of the present invention in a communications system having a

20   modem pool for communicating via a communications channel, the modem pool having a plurality of modems, a method is provided for modem pool expansion including adding a new modem into the modem pool, where the new modem is operative to communicate via the communications channel, learning crosstalk caused by transmissions from any of the plurality of modems via the communications channel to the added modem while the added

25   modem is in a transmitting state insufficient to cause crosstalk interference to any of the plurality of modems in accordance with a predefined measure, deriving from the learned crosstalk an estimation of crosstalk that would be caused by the added modem to any of the plurality of modems when the added modem is in a transmitting state, configuring any of the plurality of modems to cancel crosstalk according to the crosstalk estimation, causing the

30   added modem to enter a transmitting state sufficient to cause crosstalk interference to any of the plurality of modems in accordance with a predefined measure, and causing any of the

4

plurality of modems to at least partially cancel crosstalk caused by the added modem in accordance with the crosstalk estimation..

In another aspect of the present invention the learning step includes learning by applying crosstalk cancellation to transmissions received by the new modem at a receiver of the new modem.

In another aspect of the present invention the learning step includes expressing the learned crosstalk as a transfer function.

In another aspect of the present invention the learning step includes learning while the added modem is in a non-transmitting state

In another aspect of the present invention the deriving step includes applying an adjustment to the crosstalk estimation to compensate for a difference in a characteristic of the transmissions.

In another aspect of the present invention the deriving step includes deriving the estimation from a reciprocal value of the learned crosstalk.

In another aspect of the present invention a communications system is provided having a first modem transmitting via a communications channel, and a second modem for communication via the communications channel, the system including means for configuring the second modem for receiving communications via the communications channel, means for learning crosstalk caused by transmissions from the first modem via the communications channel to the second modem while the second modem is in a transmitting state insufficient to cause crosstalk interference to the first modem in accordance with a predefined measure, means for deriving from the learned crosstalk an estimation of crosstalk that would be caused by the second modem to the first modem when the second modem is in a transmitting state, means for configuring the first modem to cancel crosstalk according to the crosstalk estimation, means for causing the second modem to enter a transmitting state sufficient to cause crosstalk interference to the first modem in accordance with a predefined measure, and means for causing the first modem to at least partially cancel crosstalk caused by the second modem in accordance with the crosstalk estimation.

In another aspect of the present invention the means for learning is operative to learn by applying crosstalk cancellation to transmissions received by the second modem at a receiver of the second modem.

In another aspect of the present invention the means for learning is operative to express the learned crosstalk as a transfer function.

In another aspect of the present invention the means for learning is operative to learn while the second modem is in a non-transmitting state

In another aspect of the present invention the means for deriving is operative to apply an adjustment to the crosstalk estimation to compensate for a difference in a characteristic of the transmissions.

In another aspect of the present invention the means for deriving is operative to derive the estimation from a reciprocal value of the learned crosstalk.

In another aspect of the present invention a communications system is provided having a modem pool for communicating via a communications channel, the modem pool having a plurality of modems, the system including means for adding a new modem into the modem pool, where the new modem is operative to communicate via the communications channel, means for learning crosstalk caused by transmissions from any of the plurality of modems via the communications channel to the added modem while the added modem is in a transmitting state insufficient to cause crosstalk interference to any of the plurality of modems in accordance with a predefined measure, means for deriving from the learned crosstalk an estimation of crosstalk that would be caused by the added modem to any of the plurality of modems when the added modem is in a transmitting state, means for configuring any of the plurality of modems to cancel crosstalk according to the crosstalk estimation, means for causing the added modem to enter a transmitting state sufficient to cause crosstalk interference to any of the plurality of modems in accordance with a predefined measure, and means for causing any of the plurality of modems to at least partially cancel crosstalk caused by the added modem in accordance with the crosstalk estimation..

In another aspect of the present invention the means for learning is operative to learn by applying crosstalk cancellation to transmissions received by the new modem at a receiver of the new modem.

In another aspect of the present invention the means for learning is operative to express the learned crosstalk as a transfer function.

In another aspect of the present invention the means for learning is operative to learn while the added modem is in a non-transmitting state

In another aspect of the present invention the means for deriving is operative to apply an adjustment to the crosstalk estimation to compensate for a difference in a characteristic of the transmissions.

In another aspect of the present invention the means for deriving is operative to derive the estimation from a reciprocal value of the learned crosstalk.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a simplified pictorial illustration of a modem pool arrangement useful in understanding the present invention;

Fig. 2 which is a simplified pictorial illustration of elements of a modem pool arrangement useful in understanding the present invention;

Fig. 3 which is a simplified pictorial illustration of a modem pool arrangement with hitless modem expansion, constructed and operative in accordance with a preferred embodiment of the present invention; and

Fig. 4 which is a simplified pictorial illustration of a modem pool arrangement with hitless modem expansion including adjustment for different transmission characteristics, constructed and operative in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFFERED EMBODIMENTS

Reference is now made to Fig. 1 which is a simplified pictorial illustration of a modem pool arrangement useful in understanding the present invention. A modem pool, generally referenced 100, and comprising a plurality of individual modems is seen in communication with a modem pool, generally referenced 102, via a plurality of connections 104 over a telephone network 106. Connections 104 are typically copper wire pairs arranged in one or more bundles 108. The modem pools preferably operate in a coordinated manner using conventional techniques, such as is described in U.S. Patent Application No. 09/510,550 filed February 22, 2000, and entitled "High Speed Access System Over Copper Cable Plant." The interference on each connection 104, the attenuation coefficients of the crosstalk between connections 104, the attenuation of each connection 104 from end to end, as well as the bit error rate (BER) of each connection 104

7

may be measured using conventional techniques, and any of this information may be communicated to any of the modems shown, including via connections other than connections 104, such as via a back channel 116.

5   The addition of a new modem pair 110, 112 communicating via a connection 114 in bundle 108 will typically introduce crosstalk interference to the connections 104, degrading the signals sent and received by modems 100 and 102.

        Reference is now made to Fig. 2 which is a simplified pictorial illustration of elements of a modem pool arrangement useful in understanding the present invention. In Fig. 2, two modems A_1 and A_2 of one side of a modem pool are shown. As in Fig. 1,

10   modems A_1 and A_2 communicate via separate channels L_1 and L_2, respectively, of a shared communications medium (not shown), such as a telephone wire bundle, and, as such, have a crosstalk effect on each other. The crosstalk effect that modem A_1 has on channel L_2 and, as a result, on transmissions received by modem A_2, is shown as $H_{1,2}$, while the crosstalk effect that modem A_2 has on channel L_1 and modem A_1, is shown as $H_{2,1}$. $H_{1,2}$ and $H_{2,1}$ are

15   typically expressed as linear transfer functions. According to the reciprocity principle, $H_{1,2}$ and $H_{2,1}$ are symmetrical, and thus $H_{1,2}$ may be derived from $H_{2,1}$, and vice versa. A crosstalk canceller $C_{2,1}$, typically being an adaptive filter, is shown, which models the crosstalk of $H_{2,1}$ using conventional techniques and communicates this information to modem A_1. Modem A_1 may then use this information to compensate for the crosstalk it

20   experiences from modem A_2 using conventional techniques. Similarly, a crosstalk canceller $C_{1,2}$ is shown, which models the crosstalk of $H_{1,2}$ communicates this information to modem A_2 which compensates for the crosstalk it experiences from modem A_1.

        Reference is now made to Fig. 3 which is a simplified pictorial illustration of a modem pool arrangement with hitless modem expansion, constructed and operative in

25   accordance with a preferred embodiment of the present invention. In the present invention, when a modem A_N is added to a modem pool, and either before modem A_N begins to transmit a signal at all or before modem A_N begins to transmit a signal sufficiently strong enough to degrade the performance of any of the modems in the modem pool in accordance with a predefined measure, a modem A_1 in the modem pool learns the crosstalk $C_{N,1}$ that

30   modem A_N will cause to signals received by modem A_1 once A_N begins transmitting normally. To accomplish this, in Fig. 3 a signal transmitted by modem A_1 is sampled within

modem A_1 by a crosstalk canceller $C_{1,N}$. A transformator TX_1 then preferably performs a transformation upon the signal, such as by applying conventional transmission filters, and the signal is transmitted on channel L_1, being the ordinary path of the transmission signal. The crosstalk caused by modem A_1 to channel L_N of modem A_N is received by the receiver

5   of A_N, which may perform a transformation RX_N on the crosstalk received. Crosstalk canceller $C_{1,N}$ then models the concatenation of the coupling of TX_1, $H_{1,N}$ and RX_N. Due to the reciprocal nature of crosstalk between modems in a modem pool, the crosstalk information learned by $C_{1,N}$ may be used to generate a crosstalk canceller $C_{N,1}$. This is preferably accomplished by multiplying $C_{1,N}$ by the ratio $(TX_N*RX_1)/(TX_1*RX_N)$. $C_{N,1}$ may

10 then be used to eliminate crosstalk that modem A_N will cause to signals received by modem A_1 once A_N begins transmitting a signal at full power or at a power level sufficient to cause crosstalk interference to modem A_1 in accordance with a predefined measure by modeling the concatenation of the coupling of TX_N, $H_{N,1}$ and RX_1.

In this manner, a different crosstalk canceller $C_{N,X}$ may learn the crosstalk

15 caused by each modem A_X in the modem pool to modem A_N and provide the information to a crosstalk canceller $C_{X,N}$ for reciprocal cancellation of crosstalk caused by modem A_N to modem A_X.

Reference is now made to Fig. 4, which is a simplified pictorial illustration of a modem pool arrangement with hitless modem expansion including adjustment for different

20 transmission characteristics, constructed and operative in accordance with a preferred embodiment of the present invention. It is appreciated that the transmission mechanism TX_1 could differ from that of TX_N, and/or the reception mechanism RX_1 could differ from that of RX_N, having, for example, different gain or phase. Nevertheless, the linear part of the transfer functions $H_{1,N}$ and $H_{N,1}$ are expected to be identical.

25 Differences between RX_1 and RX_N may occur for several reasons. For example, RX_1 might introduce a different delay into its received signal than might RX_N. To compensate for the different delays, an adjustment element ADJ may adjust the delay in the signal received at canceller $C_{N,1}$ using conventional techniques. The difference in delays may be measured for any two modems in the modem pool at any time. Where the modems are

30 from different vendors and/or employ different technologies (e.g., SHDSL vs. ADSL), the

9

receivers and transmitters of the modems may include filters which are substantially different from one another.

Differences in both gain and delay may also be compensated for by adjustment element ADJ, such as where $C_{1,N}$ is a discretization of a continuous time filter $C_1(t)$, and $C_{N,1}$ is a discretization of a continuous time filter $C_2(t)$, which are related by the equation: $C_1(t)=g^*C_2(t+d)$, where g and d are gain and delay factors respectively. To compensate, g and d may be estimated in advance, allowing $C_{N,1}$ to be computed from g, and d, and $C_{1,N}$, using any conventional interpolation methods.

In another example of compensating for the effect of different transmission and reception mechanisms (e.g., TX_1 and RX_N), the combinations of crosstalk cancellation filters $C_{i,j}$ for each combination of TX_i and RX_j may be determined prior to activation of the modem pool. As the ratio of the transfer function of any two filters $C_{i,j}/C_{j,i}$ reflects the difference between the two TX mechanisms and the two RX mechanisms, this ratio may be expected to be the same for the crosstalk coupling measured prior to activation of the modem pool and the crosstalk coupling at steady state. Thus, the ratio $C_{i,j}/C_{j,i}$ measured prior to activation can be used by adjustment element ADJ at steady state to compute $C_{j,i}$ from $C_{i,j}$ multiplying $C_{i,j}$ by $C_{j,i}/C_{i,j}$.

In another method, the transfer functions of RX and TX are measured separately for each TX device and each RX device directly using a network analyzer. These functions may then be used by adjustment element ADJ to compute $C_{j,i}$ from $C_{i,j}$ by multiplying $C_{i,j}$ by the ratio $(TX_j^*RX_i)/(TX_i^*RX_j)$.

It is appreciated that one or more of the steps of any of the methods described herein may be omitted or carried out in a different order than that shown, without departing from the true spirit and scope of the invention.

While the methods and apparatus disclosed herein may or may not have been described with reference to specific computer hardware or software, it is appreciated that the methods and apparatus described herein may be readily implemented in computer hardware or software using conventional techniques.

While the present invention has been described with reference to one or more specific embodiments, the description is intended to be illustrative of the invention as a whole and is not to be construed as limiting the invention to the embodiments shown. It is

10

appreciated that various modifications may occur to those skilled in the art that, while not specifically shown herein, are nevertheless within the true spirit and scope of the invention.